14.1 Lidar survey of the Stonehenge World Heritage Site, UK
The lidar survey (digital surface model, including trees and buildings) is here relief-shaded from the north. Stonehenge itself lies near the centre of the frame (red arrow). Durrington Walls, the other great Neolithic enclosure referred to in the text, is at top right (yellow arrow). The Figure covers an area approximately 6.8×7.7 km.
Aerial photography has revealed, and over widening national horizons continues to reveal, the wealth of archaeological evidence that is the fundamental resource for our understanding of cultural landscapes through time. Sites ranging from small indeterminate groups of features to large settlements with associated field systems are not only being discovered but are also being placed in their landscape context; and their spatial interrelationships can also be explored. The methodology of aerial photography is well established and the underlying reasons for the appearance of sites through cropmark and soilmark evidence is well understood (Wilson 1982, 2000; Scollar et alii 1990).

Aerial archaeology is but one application of Earth Observation science. An ever-increasing range of instrumentation is being deployed to observe the geo-environment from platforms that range from low altitude small unmanned aerial vehicles to orbiting satellites. Some of the instruments are capable of providing data of distinct archaeological value. The devices may passively record reflected visible and non-visible solar radiation in specific spectral bands able to show vegetational stress, soil moisture variation etc through which archaeological sites can be identified. Alternatively, instruments may actively investigate the Earth’s surface through techniques such as microwave radar, which is sensitive to moisture levels in both plants and the soil. Radar’s ability at longer wavelengths (23.5 cm L band of the Shuttle Imaging Radar) to penetrate dry sand cover to reveal the underlying late quaternary landscape of desert regions is a well-known dramatic example of the discoveries that can be made (Lillesand, Kiefer 2000, fig. 8.27). Throughout the remote sensing industry there is an ongoing drive to improve sensing devices in both their sensitivity and image resolution. The standard text-books on remote sensing, such as that by Lillesand and Kiefer, appear in new editions with increasing regularity. Some of the new sensing techniques are now employed for archaeology, and for aerial photography itself digital technology is beginning to replace film recording. The papers presented at the NATO research workshop on Aerial Archaeology at Leszno in Poland in 2002 placed some of these developments in their context at that time (Holden et alii 2002; Shell 2002; Bewley, Raczykowski 2002). The principal purpose of this paper, which builds on a presentation given at the Aerial Archaeology Workshop at Siena in June 2001, is to show how these techniques, then in their initial stages of archaeological use, are by the time of this book’s publication in 2005 becoming established tools, and particularly to examine the application of airborne laser scanning instrumentation (lidar – light detection and ranging) as a tool for both detecting archaeological sites and digitally exploring their location in the landscape.

**Digital Imagery**

Digital imaging is replacing film-based recording in the public photographic market, and is also now an alternative to film-based photography for aerial mapping with large-format survey cameras. The images from the new digital survey cameras can be readily used with photogrammetric software to construct high-resolution digital surface models for combination with a continuous image mosaic that is exactly georeferenced to the relevant national survey coordinate system. The High Resolution Stereo Camera (HRSC) originally designed by the German Aerospace Centre (Deutsches Zentrum für Luft- und Raumfahrt, or DLR) for the survey of Mars showed its potential for earth survey in its initial airborne trials (Jaumann, Neukum 1996), and confirmed it in the collection by the airborne version (HRSC-AX) of 3D data to estimate the severity of the Oder river flood of August 1997. The camera is of the push-broom type with four
spectral bands, red, green, blue and near infrared, and panchromatic vertical and stereo recording. The image is built up from successive across track records of the ground on linear CCD arrays as the aircraft flies its survey path. The instantaneous look direction of the camera is calculated from the record made by an inertial measurement unit (IMU) of the camera’s attitude and the high-accuracy GPS positioning of the aircraft itself. The HRSC-AX is now employed for commercial survey by ISTAR in France, and Leica Geosystems has developed its ADS40 digital survey camera with the DLR from the HRSC design principles. The alternative approach to digital imaging by employing rectangular-area pixel arrays in large-format survey cameras is limited by the size of arrays currently available. Z/I Imaging and Vexcel have developed respectively their Digital Mapping Camera and the UltraCam by using multiple lens-array combinations. The images from these are merged electronically to create a large-format single image of centimetric ground resolution. The recording CCDs in all these cameras have a high dynamic range and their manufacturers suggest that part of their high cost is offset by avoiding the need to process and scan traditional film output. Technical details and image specifications for these digital survey cameras and other devices referred to in this paper can be found at the manufacturers’ websites, which are readily accessible through internet search engines.

Much early space imagery, such as that from the Landsat series of satellites, achieved a ground pixel size of the order of 30 m or greater. The Landsat 4 and 5 Thematic Mapper (TM) sensor had a multispectral capability at 30 m ground resolution including spectral bands in the near and mid infrared (LILLESAND, KIEFER 2000, p. 379). This level of resolution is capable of detecting large archaeological features and sites, but is equally of value for defining the large-area setting of sites. Declassified 1960s United States CORONA intelligence satellite photography, and the more recent Russian KVR-1000 photographic satellite (FOWLER, CURTIS 1995), with its approximately 1.5 m ground resolution, approached the resolution of aerial photography. The deployment of the very high resolution ikonos and QuickBird satellites, with a ground pixel sizes respectively of 0.6 m and 0.8-2.0 m in panchromatic mode, and four times greater multispectral ground sampling distance (GSD), has further closed the gap between digital space imaging and aerial survey photography. Whilst the coverage from these satellites is not extensive, and is discontinuous, the extensive moderate-resolution (5 m GSD) coverage of the Indian Remote Sensing IRS-1C/1D satellite is being used by EuroMap GmbH to create country-wide natural colour ortho-mosaic photomaps – so far for Germany, Switzerland and Austria, and, at the time of writing, in preparation for Italy. Similar national coverage is available for Britain from aerial photographic campaigns by Getmapping and UK Perspectives at 1 m or better GSD. Although flown to provide a national photomap this, like other commercial aerial photography, may record by chance archaeological sites visible as soilmarks and cropmarks.

**Digital Terrain Models**

All imagery can be better employed for studying the landscape context of sites if combined with a digital terrain model (DTM) of comparable resolution. This may have been derived from traditional aerial photogrammetry, as in a recent project to examine the location of the megalithic monuments in the Carnac, Morbihan, landscape in France (ROUGHLEY, SHELL 2004; ROUGHLEY 2004). Digital terrain models can also be generated by photogrammetry from suitable satellite imagery, such as the downward- and backward-looking sensors of the Japanese ASTER instrument on the NASA Terra satellite. This can provide a digital elevation model with height accuracy of 13 m RMSE from its 15 m GSD stereo imagery (CUARTERO et alii 2004). Alternatively, interferometric synthetic aperture radar (InSAR or IFSAR) measurements (LILLESAND, KIEFER 2002, pp. 687-91) can be used to directly measure the earth’s topography from the phase difference of a returning radar signal detected at two or more receiving aerials. The Shuttle Radar Topography Mission (SRTM) of February 2000 measured with C-band InSAR the height of most of the earth’s land surface every 30 m between ±60º latitude, with a vertical accuracy at best in the region of 16 m, and relative accuracy in the region of 6 m (RABUS et alii, 2003). Three arc second (~90 m) interval SRTM data is freely available from the USGS EROS Data Center for the world; 1 arc second (30 m) data is available for the United States and its dependencies. This is an enormous resource for studying the distribution of sites in their large-scale landscape context. By deploying InSAR in an aircraft, the increased proximity to the ground, just as for digital imaging devices, improves the ground sampling distance and accuracy by up to an order of magnitude. As an example, the InSAR mapping of England and Wales in Intermap Technologies’ NextMap project, has measured at 5 m GSD the ground height with a 0.5-1.0 m accuracy. The close interval of the readings allows surface features such as buildings and trees to be recognised and filtered from the
data, converting a Digital Surface Model (DSM) to a Digital Terrain Model (DTM) defining the ground surface itself. Primarily commissioned for flood modelling, the NextMap continuous terrain model of England and Wales is a major resource for visualising the topographic location of archaeological sites. The NextMap data has been merged with Getmapping 2 m colour aerial photography to create 3D Photoscape, a product which provides, on a county by county basis, the ability to interactively fly across the digital landscape and explore landscape settings. Although for commercial reasons limited in its functionality to displaying just the aerial photographic cover over the terrain model, the software is an inexpensive pointer to the future way in which the general public as well as archaeologists will be able to access and explore these types of datasets.

HIGH-RESOLUTION AIRBORNE DIGITAL SENSORS: IMAGERY AND TERRAIN MODELLING

In addition to the gradual development of very high resolution airborne sensors for imaging at centimetric GSD, airborne laser scanning (commonly referred to as lidar) has rapidly established itself as a powerful alternative to photogrammetry for terrain modelling, with its capability of measuring routinely the height of the earth’s surface at sampling intervals from 0.5 m to 2.0 m to an absolute positional accuracy in x, y, and z of 0.15 m, with the data exactly georeferenced to the universal GPS satellite (WGS84/ETRS89) or the relevant national coordinate system. High-resolution airborne imaging, including in the non-visible range, is capable of not only discovering sites, but also defining detail within them (Shell 2002). Similarly, at 1.0 m or smaller GSD, lidar detects the fine changes in relief that are the vestigial surface expression of an archaeological site, even after extensive degradation from the plough.

The UK Environment Agency (Holden et alii 2002) is able to simultaneously measure and image the ground by flying its Optech ALTM 3033 lidar in combination with a multispectral Compact Airborne Spectrographic Imager (CASI 3). The University of Cambridge Unit for Landscape Modelling can fly its Optech ALTM 3033 lidar with either a Zeiss LMK15 aerial survey camera or two Thales Optronic 8010 wide-band sensors in a filtered spectral mode for image acquisition. Whilst it is of value to have combined image and topographic data, the optimum conditions for archaeological survey may differ.

Lidar is able best to penetrate deciduous tree cover in a leafless state, and similarly measure ground height when there is minimal vegetation-cover. Winter is an appropriate time for detecting soilmarks in arable fields, but airborne imaging sensors more readily detect sites during the periods of cropmark formation.

HIGH-RESOLUTION AIRBORNE SENSING

Apart from a direct, visible, colour difference due to the material from the buried site being brought to the surface by the plough, soilmarks may be visible through differential drying or temperature variation that reflects local soil-moisture variation and the associated difference in thermal capacity (Scollar et alii, 1990; Shell 2002). The soil moisture and thermal capacity combination can also affect the first appearance of cropmarks in a winter-sown cereal, with the higher soil moisture and temperature assisting germination and initial growth. In the later stages of growth, the plant’s response to stress, as measured in its varying spectral reflectance of sunlight (Fig. 14.2, 14.3), is due either to a direct relationship with the leaf moisture content, or its effect on the leaf’s physiology. The reflectance in the short-wave (mid) infrared range

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(1.3–2.5 m) is largely governed by the leaf moisture content itself (Ripple 1986), whereas its effect is indirect in the visible (0.4–0.7 m) and near infrared (0.7–1.3 m). The red light reflectance is increased by a reduction of chlorophyll levels as the moisture stress increases, and the increased near-infrared reflectance results from stress-induced changes in the leaf’s cellular structure. Fig. 14.4 shows the contribution of the enhanced near-infrared reflectivity of a winter wheat crop in defining the narrow ditch structure of a Neolithic long barrow (burial mound). There was no visible cropmark in the field at the time. The image was obtained with a Thales Optronics 8010 wide-band push-broom electron-optical sensor in panchromatic mode, with a GDS in the region of 3 cm.

A plant’s ability to respond to the heating effect of sunlight is also directly related to its access to water, which it uses to control its temperature by evapotranspiration. With increased drying of the soil, a plant will eventually show signs of wilting and an accompanying colour change. Thermal sensors can directly measure plant temperature differences associated with varying water content (Soil Moisture Deficit) of soils across an archaeological site. Fig. 14.5, in an image synchronous with Fig. 14.4, shows the lower temperature (darker grey) of the winter wheat growing over the deeper humic soil of the ditch enclosing the Swaffham Prior long barrow; it also shows details of a nearby linear pit-alignment. The Thales Vigil thermal linescan has a temperature sensitivity of better than 0.16 °C equivalent temperature, and 20 cm GSD when flying at 300 m altitude (Shell 2002). In thermal imaging, the plant is effectively sampling the moisture regime to the depth to which its roots have grown. The rooting system of a cereal such as wheat can penetrate to depths greater than a metre, depending on the soil moisture availability at the time it is developing. In contrast, grass in grazed pasture may have root systems that are confined to 30 cm of topsoil. The left-hand part of Fig. 14.6 shows a thermal linescan image of a pair of curved hollow ways (sunken trackways) in permanent pasture at the Wandlebury hillfort, south of Cambridge, in eastern England. The corresponding geophysical survey (Fig. 14.6, right), undertaken with a fluxgate gradiometer (Gaffney, Gater 2003), similarly defines the hollow ways but additionally shows the higher magnetic response of several deep Iron Age pits. These pits are not apparent in the thermal image, probably because of the limited sampling depth of the grass. A calculation based on the local early summer rainfall record shows that the thermal detection of the hollow ways is occurring at a Soil Moisture Deficit (SMD) that is at least
20% lower than that required for visible parching of the grass (Evans, Jones 1977). From this we can see that thermal imaging may be much more successful in detecting sites in regions where the SMD rarely reaches the level necessary for grass parch marks to form.

The CASI 3 multispectral scanner can image the ground in up to 288 wavelength bands, subdividing the visible and near infrared regions of the spectrum between 0.43 m and 0.90 m. In practice 15–20 bands are used, and these can be selected to monitor the wavelengths most sensitive to plant-growth conditions. The best attainable GSD is in the region of 1 m, with a swath width (striscia) of 500 m. In this it corresponds closely to airborne lidar’s ground sampling interval. A GSD of 1 m is not adequate for defining the finer features of sites, but may readily show the strong contrast between bare soil and vegetation that is useful in monitoring erosion and animal damage.

**High-resolution airborne terrain modelling with lidar**

Airborne lidar is one of the most important innovations in airborne sensing in recent years and its value for archaeology can be immediately recognised. The technique is a development of the optical distance measurement that has been in common use in ground survey with total-station instruments for over twenty years. The distance to an object is calculated from a very accurate measurement of the time taken for a pulse of laser light to reach the target and be reflected back. In airborne lidar the laser beam is scanned from side to side as the aircraft flies a pre-planned pattern over the survey area, measuring between 20,000 and 100,000 points per second. The scan angle is restricted to 10 to 15 degrees to minimise obscuration of the ground by closely-spaced buildings and trees. Typically, with the aircraft flying at 1000 m altitude and 120 knots (62 m/sec) ground speed, a scan angle of 12 degrees with 40 scans per second and 33.333 measurements per second will measure the distance to the ground every 0.8 to 1.0 m, with a positional accuracy in x, y and z in the region of 15 cms. The laser beam is about 25 cm in diameter and may encounter buildings, or a branch or leaves of a tree as well as the ground below it (Fig. 14.7). The lidar records the first and last pulse measurements and the intensity of the reflected beam. This builds up a very accurate, very high-resolution digital surface model of the ground and the features upon it. The surveyed swath (striscia) is about 450 m wide, and is flown with a 20–25% side overlap to avoid loss of data from the continuous changes in the aircraft’s attitude in flight. A small number of cross-swaths is flown to assist in the matching of adjacent swaths in the post-processing.
The aircraft’s position in the air and the changes in its attitude must be known with the highest possible accuracy in order to calculate the position of each laser-measured point. For this, the lidar system has a very accurate dual-frequency global positioning system (GPS) recording the aircraft’s position every second and an inertial measurement unit (IMU) recording the aircraft’s roll, pitch, yaw and heading up to 200 times per second (Fig. 14.8). The position of the aircraft is determined by reference to a GPS ground station located for best accuracy within 20 km of the survey, recording the same GPS satellite constellation as the aircraft. The position of the ground station must be known to a high accuracy; ideally it is located on a pre-surveyed GPS reference point of the national survey grid. Otherwise the reference position must be determined with a high-precision static GPS survey (Holden et alii 2002). It is only in these best circumstances that the absolute accuracy of the measured points is in the region of 15 cm. The relative accuracy of adjacent readings is higher. The first and last pulses coincide when the ground surface is measured, but may be separated where trees are encountered (Fig. 14.9).

The lidar data can be retained as the original point measurements, from which can be created a triangular irregular network (TIN) surface model, often used with 3D visualisation software; alternatively the data can be converted to a regular grid of a specific spacing with interpolation of missing data where it may occur. In grid form the digital surface model is more readily integrated with other vector data and raster imagery in GIS and Remote Sensing software. The UK Environment Agency supplies its data in 2 km by 2 km Ordnance Survey National Grid squares. There is no standardised procedure for gridding lidar data, and it must be remembered that height errors of up to 1 m may be introduced by some types of gridding procedure (Smith et alii 2004). Many existing lidar datasets have been recorded at a 2 m average GSD, which is sufficient resolution for flood hazard modelling, but does not reveal details of archaeological features as clearly as 1 m interval data, which should be preferred. Higher-resolution, 0.5 m, GSD data is capable of revealing further fine detail, such as relict cultivation marks in modern pasture (Shell, Roughley 2004).

The most direct way of viewing the lidar data is to represent the height by either colour coding, or by use of a continuous grey scale. Fig. 14.10 is a height-shaded lidar DSM of the Stonehenge World Heritage Site (WHS) from a survey undertaken to investigate lidar as a tool for augmenting existing aerial techniques (Bewley et alii forthcoming). The height-shading of the 1 m GSD data clearly shows...
the Avon river valley and the related dry-valley system of the surrounding landscape, with higher ground to the north. Areas of woodland and the cuttings and embankment of the A303 road to the east of Stonehenge are visible but lack detail. It is self-evident from aerial photography that details of low earthworks are greatly enhanced by low oblique sunlight. The advantage with lidar data is that the digital surface model can be relief-shaded with a digital sun from any direction (azimuth) and elevation, including from the north, and the image contrast can be adjusted as required. Relief-shading reveals the depth of fine detail of the topography recorded by the lidar (Fig. 14.1). The major monuments are made visible, including Durrington Walls Neolithic henge monument (ceremonial enclosure), as well as the Early Bronze Age barrow cemeteries and extensive field systems in the modern arable fields in the west of the survey area. Lidar detects the slight surviving surface evidence of features, even where they are greatly reduced by the plough. Fig. 14.11 illustrates this, where a complete field system to the west of the Lake barrow cemetery is seen to survive as broad slight earthworks that measure only 30-40 cm in height.

The lidar survey of the Stonehenge WHS has identified several new features in a landscape already extensively surveyed, including through a detailed transcription of the aerial photographic record as part of the English Heritage National Mapping Programme (Bewley 2003; Bewley et alii forthcoming). As well as detecting surviving field systems in arable fields, lidar is equally able to reveal relict field boundaries in pasture, even where the land has been improved. From a study of the Loughcrew landscape, Co Meath, Ireland, (Shell, Roughley 2004), Fig. 14.12 shows enclosures and ancient field boundaries in pasture improved by stone-removal and ploughing. A length of over 150 km of...
field boundaries has been transcribed from the 5 km by 6 km lidar survey area. Modern features such as field boundaries, buildings and woodland are included in the lidar digital surface model. These may be removed from the data to create a digital terrain model, a model of the ground surface itself, which may more readily represent the landscape in which the monuments were originally constructed, and facilitate the study of the potential visual inter-relationships between the sites. Much of the woodland in the Stonehenge WHS has been planted in the last 200 years, in some cases to screen new buildings so that they cannot be seen from Stonehenge. The woodland itself may contain surviving archaeological earthworks. Where there are sufficient lidar last-pulse measurements reaching the ground surface, a reasonable digital terrain model can be generated by filtering from the data the higher elevations that are the reflections from the trees. This has revealed, for example, field boundary banks and the line of a former military railway in Fargo Plantation, in the Stonehenge WHS (Fig. 14.13). The boundaries form part of a field system now known to incorporate part of the western end of the long Neolithic monument known as the Stonehenge Cursus (BEWLEY et alii, forthcoming).

**LIDAR AND LANDSCAPE RESEARCH**

Software for GIS and Remote Sensing has a number of capabilities that can enhance our exploration of lidar data. An example of this is the calculation of a “viewshed” from particular point in the digital landscape that shows which areas are visible from that point, and which are not. A viewshed calculated from the centre of Stonehenge using the digital terrain model with trees and buildings removed (as well as the stones of the monument), shows us the extent of the landscape from which the monument can be seen when unhindered by trees (Fig. 14.14). From this it is apparent that the view from Stonehenge along the ritual Avenue in the direction of mid-summer sunrise reaches 2.75 km to a point on Durrington Down that is just 500 m from the western entrance to the great enclosure at Durrington Walls. Without the intervening trees and buildings, at midsummer any observer from here would see Stonehenge being lit up by the sun rising at their backs. Similarly, the topographic positioning of monuments such as Neolithic long barrows (elongated burial mounds) can be investigated by plotting their location on the relief-shaded lidar image (Fig. 14.15). The locational information has been augmented by 1 m interval raster contours generated from the lidar DTM and with it we can see how the group of seven Neolithic long barrows in the western part of the WHS occupy very specific locations on the forward slopes of ridges around the western arm of the dry-valley system. Computer visualisation of the digital landscape can be used interactively to study monument locations and their spatial inter-relationships, especially if the lidar terrain model is draped with informative imagery such as that from CASI or aerial photography, or vector information from the local Sites and Monuments Record. Fig. 14.16 shows a section of the Loughcrew Project’s 0.5 m GSD lidar...
14.13 Relief-shaded digital terrain model, Stonehenge World Heritage Site, UK
Shaded from the northwest, showing ancient field banks and the course of a recent military railway (top left) in Fargo Plantation, as seen when trees (inset diagram, red) are removed from the lidar dataset. Across the lower part of the image can be seen the earthworks of the Stonehenge cursus monument and Early Bronze Age burial mounds.

14.14 Viewshed plot within the Stonehenge World Heritage Site, UK
Plot of the viewshed calculated from a height of 1.5 m above the centre of Stonehenge (yellow circle, bottom left). Trees, buildings and the stones of the monument itself have been removed. The viewshed marks in green the areas that are not visible from Stonehenge. It is displayed over the relief-shaded digital surface model and overlain with the vector data from the Wiltshire County Sites and Monuments Record (yellow). The huge Neolithic enclosure of Durrington Walls lies at top right.
model, draped with the orthorectified mosaic of 0.20 m GSD vertical aerial photography that has been georeferenced to the Irish national survey grid. The view shows the landscape southward to the Slieve na Calliagh hills, upon which are located the Neolithic passage-tombs at Loughcrew (Shell, Roughley 2004). Whilst visualisation has an important research role, it also can present the immediacy of the landscape to the general public, both for education and as a tool in the processes of planning and landscape management.

LIDAR SURVEY AND REMOTE SENSING IN PLANNING AND MANAGEMENT

Both the relief-shaded lidar image of the Loughcrew landscape and the Stonehenge WHS digital visualisation are able to convey immediately to the viewer the presence and distribution of surviving archaeological remains; through this the potential impact of a proposed development or change in agricultural regime can be better understood. Realistic models of proposed developments can be incorporated into such visualisations so that the public can assess and comment on their impact. Similarly, forestry managers can evaluate the impact of future woodland planting proposals. Agriculture has been identified as the single greatest threat to the survival of England’s most valuable sites (Trow 2003). Under new conservation-oriented agricultural support schemes farmers may be rewarded for preserving archaeological sites and taking out of cultivation such areas as the early field system in the Stonehenge World Heritage Site, where field boundaries can be seen from the lidar data to survive despite years of ploughing (Fig. 14.11). Investigations have also been carried out in the use of combined CASI imagery and lidar for managing the archaeological monuments in the Salisbury Plain military training area immediately to the north of the Stonehenge WHS (Barnes 2003). The training area requires the monitoring of both the historic and natural environment in its integrated management plan, seeking evidence of changes in bare ground, excessive grazing and disturbance by both military and animal digging.

The United Kingdom Highways Agency’s currently proposed road-improvement scheme for the Stonehenge area includes placing the A303 road in a tunnel south of Stonehenge and in a long cutting to the west, inside the boundary of the World Heritage Site. The new tunnel and cuttings were modelled within the Stonehenge lidar DSM (Fig. 14.17) to study the impact of the scheme on the setting of the monuments in the western part of the World Heritage Site. At the Public Inquiry into the scheme it was possible to demonstrate that a supposed beneficial effect of the scheme on the setting of the Early Bronze Age burial mound known as the Bush Barrow, in the Normanton Down cemetery, was predicated on the long-term maintenance of woodland that blocks the view between Bush Barrow and the cemetery at the Winterborne Stoke Crossroads to the west. Removal of this woodland would not only re-establish the visual relationship between the two cemeteries, but would also bring into sight a significant section of the proposed western road-cutting if built as planned (Fig. 14.18).
CONCLUSION

The contribution of digital remote sensing to archaeology is in the spheres both of research and conservation. Whilst there have been significant advances in digital sensors, including the development of digital large-format survey cameras, the principal new development has been the introduction of airborne lidar. As well as its use for archaeological site prospection and site location analysis, using established software tools such as the calculation of viewsheds and the study of monument inter-relationships by landscape visualisation, airborne lidar has equal value for resource management and landscape planning. The use of lidar data in reconstructing past environments must always be undertaken with caution, but equally lidar terrain modelling has an assured position in future understanding of past landscape change.

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14.17 Digital terrain model of part of the Stonehenge World Heritage Site, UK
Lidar digital terrain model with proposed A303 Stonehenge Road Improvement Scheme included. The road would be placed in a tunnel by Stonehenge and the area around it restored to grassland. Copyright: United Kingdom Environment Agency.

14.18 Viewshed from Bush Barrow, Stonehenge World Heritage Site, UK
Viewshed from by the Early Bronze Age burial mound, Bush Barrow (red arrow), in the Normanton barrow group (mounds to right of arrow), calculated using the lidar digital terrain model. This shows that, with the intervening trees removed, the aligned mounds of the Winterborne Stoke Crossroads barrow cemetery are visible on the western skyline at extreme left, and also the extent to which the western cutting of the A303 Stonehenge Road Improvement Scheme would be seen if constructed.